# Calibrate a power supply with a digital potentiometer

## Understand how to configure, size, and use the digital pot in this common situation

**David Fry,** *Strategic Applications Manager*, Maxim Integrated Products

A resistive feedback network is often used to set the output voltage of a power supply. While a mechanical potentiometer (pot) conveniently solves the problem of adjusting a power supply, it can be replaced with a digital pot for easier automatic calibration.

This article presents a calibration solution that uses a digital pot, because digital pots are smaller, do not move with age or vibration, and can be recalibrated remotely. This proposed solution reduces the susceptibility of the system to the tolerance of the digital pot's end-to-end resistance, making the solution optimal for designers. The article also explains some of the equations required to calculate the resistor chain values and to use a digital pot in this way. A spreadsheet with standard resistor values is available for easy calculations.

## Conventional power-supply feedback

A power supply is often designed using resistive feedback to set the output level. There are, however, many device tolerances that can affect the output voltage, so a fixed resistor-divider is often insufficient. In these situations, a variable-resistor ratio is used so the system can be calibrated during final testing.

Although a mechanical pot would have traditionally been used for this task, those components have been replaced by digital pots in many applications. Digital pots do not suffer from aging effects and are far simpler to adjust automatically.

Fixed-resistor and mechanical-potentiometer schemes are shown in **Figures 1** and **2**. .

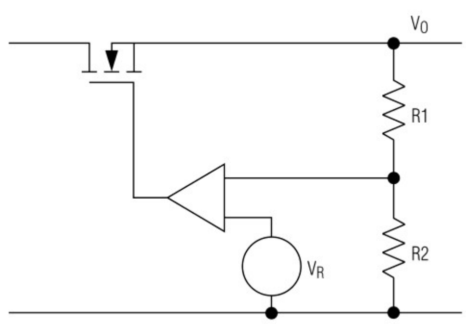


*Figure 1. A conventional fixed-resistive feedback.*

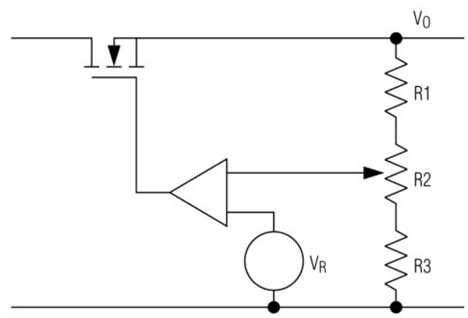


*Figure 2. A conventional variable-resistive feedback.*

Take the typical example of a 12V supply with a 2.5V reference voltage. The reference voltage and all other devices in the system will have a tolerance. Conveniently, all tolerances can be represented as additional tolerance on the reference. For this example, we will use a ±5% typical total tolerance for the reference.

Calculating the values for a fixed-resistive feedback is based on an easy equation:

$$V_O = V_R \times \frac{R1 + R2}{R2}$$

................................................. (Eq. 1)

Since in this example $V_R$ will have a tolerance of ±5%, this leads to a tolerance in the output voltage of 5%. If this is not acceptable in the application, the resistive-divider needs to be made variable. Simply replacing R1 and R2 with a mechanical pot is not normally done, since it would result in a wide range of output voltages and would be very sensitive to adjustments.

Over time and temperature, any drift in the pot's position would create an unacceptable amount of output voltage drift. Therefore, Figure 2 illustrates a scheme that reduces the output range, which is now easier to adjust and is more stable.

Hypothetically, we should be able to replace R2 with a digital pot, and we should have an electrically adjustable system. However, it is not as simple as that. First, some explanation of digital pots is required.

## Basic Structure of Digital Pots

A digital pot is normally a string of resistors with a switch at each node, as shown in **Figure 3**. For simplicity, the switches are shown as single MOSFETs. Typically, these switches would be two BiCMOS transistors (one P and one N) to produce low on-resistances.

This structure is commonly used for pots up to 256 taps. When the pot is above 256 taps, it can be more efficient to use a more complex segmented structure. However, that is beyond the scope of this article.

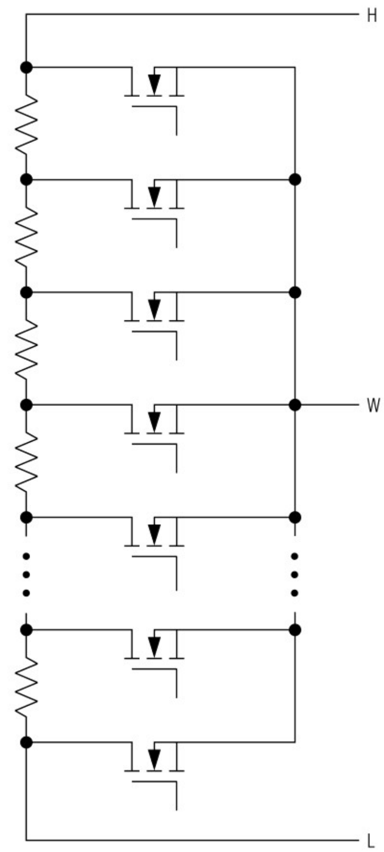


*Figure 3. A conventional fixed-resistive feedback.*

Since all resistors are manufactured on the same die, they will be very closely matched. Unfortunately, the end-to-end resistance may not be so well defined.

A typical digital pot is the MAX5402, a single-channel, 256-tap device with end-to-end resistance of 10kΩ (typical). The end-to-end resistance tolerance, however, is ±20%. Ratiometrically, it is far better defined with integral nonlinearity (INL) of 0.5 LSB (max). It is, therefore, well suited to be used as a potential divider.

## Using the digital pot to calibrate a power supply

The method to calculate the resistor values R1, R2, and R3 is shown in **Figure 4**. We will use the following example:

$V_O$ = 12V
$V_R$ = 2.5V ±5%
$R_T$ = R1 + R2 + R3.

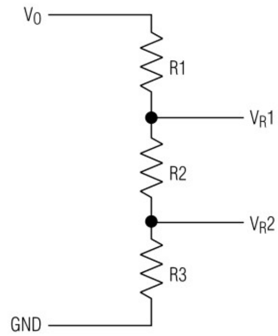


*Figure 4. The initial resistor string.*

The initial equations are simple and defined below:

$$V_R2 = V_O \times \frac{R3}{R_T} \Rightarrow R3 = \frac{V_R2 \times R_T}{V_O}$$ .................. (Eq. 2)

$$V_R1 = V_O \times \frac{R2 + R3}{R_T} \Rightarrow R2 = \frac{V_R1 \times R_T}{V_O} - R3$$ .... (Eq. 3)

$R1 = R_T - R3 - R2$ .................................................(Eq. 4)

The first step is to define a total resistance for $R_T$ using (R1 + R2 + R3). Since this is arbitrary, we will start with $R_T$ = 20kΩ. (We can always change it later to give more realistic values for R1, R2 and R3 if required.) From Equation 2, we find R3 = 3.958kΩ. From Equation 3, R2 = 417Ω, and from Equation 4, R1 = 15.625kΩ.

Clearly the ideal resistor values calculated will not generally be available, so standard resistor values need to be used. The closest 1% values are substituted for R1 and R3: R1 = 15.8kΩ, R3 = 3.92kΩ. For convenience, we have included standard resistor value charts in the spreadsheet. (http://www.eetimes.com/ContentEETimes/images/design/C0957-spreadsheet.xlsx)

Now we can calculate backward to find an ideal value for R2, as shown in Equation 5. R2 will eventually become variable. Thus, its value is calculated so that $V_O$ will be correct when R2 is cantered, and $V_R$ is at its nominal value.

$$R2 = \frac{V_O \times R3 - V_R \times R3 - V_R \times R1}{V_R - V_O/2}$$ .................(Eq. 5)

Therefore, R2 = 646Ω.

We need to account for the fact that digital pots have a very poor end-to-end tolerance. Using a large-value digital pot in parallel with a small-value fixed resistor is a simple and effective method of reducing the pot's poor end-to end tolerance. This is illustrated in **Figure 5**. Thus, the parallel combination of R2a and $R_P$ makes R2.

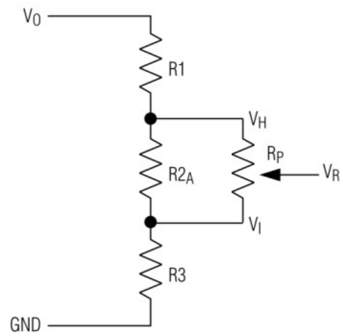


*Figure 5. The final resistor string.*

Using Equation 6, the final step is to calculate the value of the parallel fixed resistor, given a potentiometer nominal end-to-end resistor.

$$R2_A = \frac{R_P \times R2}{R_P - R2} \quad \text{.............................................(Eq.6)}$$

So, using a 10kΩ pot for $R_P$, the ideal value for $R2_A$ is 690Ω. The closest 1% value is 698Ω. If we calculate the parallel combination of this and the digital pot at its tolerance extremes, we get $R_{MIN}$ = 642Ω and $R_{MAX}$ = 660Ω. This is a tolerance of only 1% because of the 20% end-to-end tolerance of the pot. We use a 698Ω resistor for $R2_A$, as this is the closest standard 1% value.

The final calculation confirms that with real values, the digital pot can cover the required range of 5% for the reference tolerance. We can use the star-delta transformation, as shown in **Figure 6**. We obviously do not need to calculate R6.

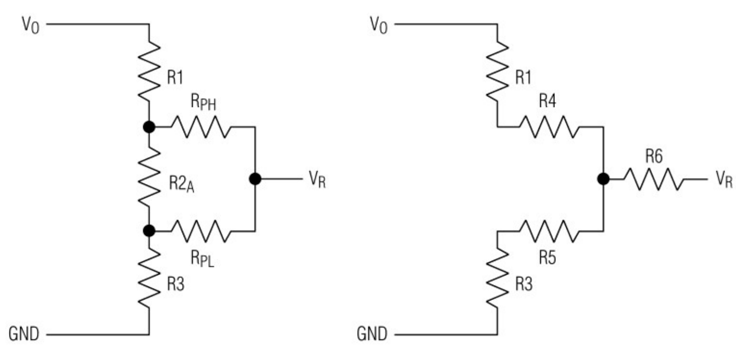


*Figure 6. Using the star-delta transformation.*

$$R_{PL} = \frac{R_P \times N}{N_{MAX}} \quad \text{...............................................(Eq. 7)}$$

Where N is the tap position and $N_{MAX}$ is the maximum tap position.

$$R_{PH} = R_P - R_{PL} \quad \text{............................................(Eq. 8)}$$

$$R4 = \frac{R_{PH} \times R2_A}{R2_A + R_{PH} + R_{PL}}$$ ..................................(Eq. 9)

$$R5 = \frac{R_{PL} \times R2_A}{R2_A + R_{PH} + R_{PL}}$$ .................................(Eq. 10)

$$V_O = \frac{V_R \times (R1 + R3 + R4 + R5)}{R3 + R5}$$ ....................(Eq. 11)

Using these equations, we confirm that the pot's range will cover the tolerance range for the reference.

To summarize the requirements and the component values selected:

$V_O$ = 12V (output voltage)
$V_R$ = 2.5V ±5% (reference voltage)
R1 = 15.8kΩ (upper resistor)
$R2_A$ = 698Ω (parallel resistor)
$R_P$ = 10kΩ (digital pot)
R3 = 3.92kΩ (lower resistor)

The following tap points set the required output voltage at the extremes of reference tolerance.

$V_R$ = 2.375V, tap = 44, $V_O$ = 11.99842V
$V_R$ = 2.625V, tap = 210, $V_O$ = 11.99773V

It may be possible to optimize this further to reduce the output voltage steps. However, the potentiometer does have some overhead at either end to take account of any further tolerances.

## Summary

This article has discussed the problem of adjusting a power supply and how this problem can be conventionally solved with a mechanical pot. Additionally, the article explains a calibration solution that uses a digital pot, since digital pots are smaller, do not move with age or vibration, and can be recalibrated remotely. This proposed solution also reduces the tolerance of the digital pot's end-to-end resistance, making the solution optimal for designers. The equations required to calculate the resistor chain values were developed and a spreadsheet is available that contains standard resistor value charts.

**About the Author**
***David Fry*** is the Strategic Applications Manager for the DACs, pots, and references product line at Maxim Integrated Products. He has over 25 years experience in the electronics industry, with the last 13 years working in semiconductor field applications, market development, and product-line applications. Prior to joining Maxim, David spent 11 years as a board-level designer working on RF designs and several years designing high-end broadcast video equipment. He earned a BSc in Electronics in 1984 from the University of Manchester Institute of Science and Technology.